Co-funded by the Intelligent Energy Europe
Programme of the European Union

Contract N°: IEE/11/845/SI2.616378

Bringing Europe and Third countries closer together through renewable Energies

BETTER

D3.2.2: Criteria and Guidelines for Sustainable Electricity Scenarios

Project Coordinator: ***CIEMAT***

Work Package ***3*** *Leader Organization:* ***DLR***

June 2013

Co-funded by the Intelligent Energy Europe Programme of the European Union

Contract N°: IEE/11/845/SI2.616378

Project Acronym: BETTER

Bringing Europe and Third countries closer together through renewable Energies

D3.2.2: Criteria and Guidelines for Sustainable Electricity Scenarios

June 2013

Project Coordinator: ***CIEMAT***

Work Package ***3*** *Leader Organization:* ***DLR***

Authors: *Franz Trieb (DLR)*

PREFACE

BETTER intends to address RES cooperation between the EU and third countries. The RES Directive allows Member States to cooperate with third countries to achieve their 2020 RES targets in a more cost efficient way. The core objective of BETTER is to assess, through case studies, stakeholders involvement and integrated analysis, to what extent this cooperation *can help Europe achieve its RES targets in 2020 and beyond, trigger the deployment of RES electricity projects in third countries and create win-win circumstances for all involved parties*.

The case studies focusing on **North Africa, the Western Balkans and Turkey** will investigate the technical, socio-economic and environmental aspects of RES cooperation. Additionally, an integrated assessment will be undertaken from the "EU plus third countries" perspective, including a quantitative cost-benefit evaluation of feasible policy approaches as well as strategic power system analyses. Impacts on the achievement of EU climate targets, energy security, and macro-economic aspects will be also analysed.

The strong involvement of all relevant stakeholders will enable a more thorough understanding of the variables at play, an identification and prioritisation of necessary policy prerequisites. The dissemination strategy lays a special emphasis on reaching European-wide actors and stakeholders, well, beyond the target area region.

PROJECT PARTNERS

N°	Participant name	Short Name	Country code
CO1	Centro de Investigaciones Energéticas, Tecnológicas y Medioambientales	CIEMAT	ES
CB2	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.)	DLR	DE
CB3	Energy Research Centre of the Netherlands	ECN	NL
CB4	JOANNEUM RESEARCH Forschungsgesellschaft mbH	JR	AT
CB5	National Technical University of Athens	NTUA	GR
CB6	Observatoire Mediterranéen de l'Energie	OME	FR
CB7	Potsdam Institute for Climate Impact Research	PIK	DE
CB8	Vienna University of Technology	TUWIEN	AT
CB9	United Nations Development Program	UNDP	HR

TABLE OF CONTENTS

1. INTRODUCTION

The present paper describes how the TRANS-CSP (2006) and MED-CSP (2005) scenarios for 50 countries in Europe, Middle East and North Africa were built by DLR and what guidelines for sustainability have been followed. The method will be used for the bottom-up scenarios created within the North Africa case study of the BETTER project.

Our scenarios are not considered as predictions of the future, but rather as consistent pathways towards a long-term target defined by a set of criteria that describe a sustainable supply of electricity. The main pillars of a sustainable electricity scenario are affordability, security of supply and compatibility with society and environment. Each scenario leads to a mix of supply options that fulfills the sustainability criteria applied and respects eventual limiters.

The pathway towards sustainability described by such a scenario must be free of contradictions and inconsistencies and is narrowed down by technical, economic, social and environmental constraints, so called guard rails. A limited portfolio of electricity supply options is available to follow those guard-rails towards a sustainability target.

The sustainability target function is defined by the following parameters:

1. Affordability
2. Security
3. Environmental compatibility
4. Social compatibility

These parameters are described in more detail in the following:

2. AFFORDABILITY

2.1. LOW COST SUPPLY

In the beginning of the study work we thought that "competitiveness" was the economic target any technology should aim at, following the paradigm of "competitive, secure and sustainable supply" of the European Union. However, after some investigation, we found that conventional competitors for power generation (fossil fuels and nuclear power) are highly volatile and unpredictable in terms of cost, with a clear upwards trend (over 400% fuel cost escalation since the year 2002, extremely high nuclear decommissioning cost surpassing commissioning cost by two to three times, etc.). To be competitive with something rather volatile that becomes more expensive every year is not a reasonable sustainability target, as such a target function would seek for solutions with ever increasing cost. Therefore, we changed our economic target towards the fixed electricity cost level of the year 2000, which was rather low. This goal was not fully achieved in every case, but as a consequence of setting such a fixed goal, the development of costs in our scenarios showed a clear stabilization of cost in the medium term and in the long term even a slow trend downwards towards the cost levels of the year 2000 (when shown in real monetary value without inflation).

2.2. NO SUBSIDIES

General predictions of world market prices were taken from sources like the IEA for all fossil and nuclear fuels, taken into consideration regional constraints (e.g. natural gas price oriented at Russia and Algeria rather than the U.S. market). Fuel prices below world market price are considered as subsidization, as a country could sell the fuel at higher price or even would be forced to import fuel once the national resource is depleted (this indeed happened lately in Egypt, which is now importing gas from Algeria, or even worse in Jordan, which is now importing fuel oil for power generation in order to substitute low cost gas imports from Egypt). In spite of using the (extremely low) IEA predictions for global fuel market prices of the year 2005 World Energy Outlook as reference for our scenarios, the introduction of (initially more expensive) renewables showed in every case a clear national economic advantage over following a subsidized fuel track. The philosophy behind not allowing subsidies is that a national economy will pay for the full price in one way or the other. In principle, external costs must also be considered as a form of subsidy, but were not considered up to now as they are rather difficult and controversial to be quantified.

2.3. NO CHEAP SOLUTIONS

The MED-CSP and TRANS-CSP scenarios are not built on any cost optimization algorithm, because of several reasons:

1. A power park is highly non-linear, there are many shut downs, part-load effects and other non-linearity's, which are very difficult to model correctly with linear optimization tools.
2. Cost differences between several technical options, that a linear optimization algorithm would use to select one or another technology, are usually smaller than the accuracy of

future cost estimates, so error propagation would lead to significant mistakes. Moreover, the time and level of cost learning curve crossings of several technologies are un-predictable.

3. Optimization of a future power park would require the consideration of its development in all prior years from today on, which was not possible at that time using normal computers. Even today this is still a challenge and requires a lot of computing time.

4. Least cost optimization will compulsively lead to the cheapest possible solution that however will not necessarily be a sustainable one. On the contrary, cheap products and cheap infrastructure often lead to severe problems for environment and society.

5. Another problem of optimization is the setting of the right target. If one optimizes for 20, 50, 80 or 100% renewable energy share one will get completely different results that may not be interconnected and may not lead from a lower share to a higher one. As an example, optimizing the way to 80% of the earth's highest mountain, the Everest (8840m), may lead to the Aconcagua (6960m) in South America, as it is much easier to access. In order to finalize the last 20% to the top, one must go down again, cross the ocean at zero meters above sea level and finally climb the total 100% in Asia: a very long way round the actual goal.

Therefore, our target was set to achieve a high quality of supply at a reasonable price, while at the same time aiming at the general low cost level of supply of the year 2000, as described before. "Quality" is defined by the set of sustainability criteria described here. This approach has led to scenarios that almost naturally allow for a short term market introduction of rather expensive supply options (like PV or CSP), always under the condition that they contribute significantly to the achievement of the sustainability target (that includes an overall low cost of supply).

3. SECURITY

3.1. DIVERSIFICATION OF SUPPLY

An important element of supply security is the diversification of supply. The more uncorrelated options a supply structure has, the more robust it is against any disruptions, e.g. increasing world market prices, scarcity induced by regional conflicts, damages by natural events, etc. Therefore, even if two different energy portfolios would lead to the same result in terms of all other sustainability criteria, a scenario with a more diversified mix would get the preference in our target function. Diversification of a national electricity mix with external sources was accepted only if local resources offering an equivalent quality of supply were not sufficient to cover the demand.

3.2. POWER ON DEMAND AND SYSTEM REDUNDANCY

Electricity must be supplied exactly on demand. This means that at any time and place, the power capacity demanded by consumers must be met by power suppliers. It is not sufficient to produce the same amount of electricity as is consumed during a certain time period, satisfying e.g. an annual energy balance in terms of kWh/y produced and consumed. It is equally important that at any moment in time the available power capacity (in terms of kW) is equal or larger than the actual load.

A simple approach to achieve this is to identify the capacity credit (CC) of each element of a portfolio (e.g. for PV, the capacity credit is zero, as there is no power at night, while for coal plants, a CC of 90% of the installed capacity can be assumed, considering that about 10% of all plants would not be available due to overhaul, outages, maintenance etc.). The cumulated capacity credit of all elements of the power park must then be larger than the peak load (the maximum load that occurs once a year) plus a reasonable reserve capacity (e.g. 125% of peak load). This approach guarantees an electricity mix that is capable of providing sufficient power capacity at any time, even if 25% of the firm capacity would be lost for some reason. Such an approach forces the installation of sufficient firm and flexible power capacity (from renewable and/or fossil sources) and has a strong impact on a scenario`s power plant portfolio. The addition of sufficient firm capacity is especially important in the countries of the MENA region that show a strong growth of (peak) demand of 5-8% per year.

3.3. SUSTAINABLE ENERGY RESOURCES

A sustainable energy scenario must be based on sustainable resources. Depletable sources may be used in the short and medium term as a bridge to a sustainable future, but must in the long term be substituted by really sustainable alternatives. This fact is easy to understand, if one recognizes that the only real “source of energy” on this planet is the sun, driving also wind, hydropower and biomass power. Most of the other available forms of energy are stored (and thus depletable) forms of energy (like fossil fuels that are in principle solar energy that was stored within hundreds of millions of years). The logic of this thought leads to the idea that a sustainable energy scenario must in the long term be based on renewable energy sources and must only be complemented by fossil fuels when absolutely necessary. This will help to empty the world’s ideal fossil energy storage as slowly as possible.

3.4. AVAILABLE TECHNOLOGY

Security of a scenario also implies that the target can certainly be achieved. Introducing any technological or systematical break-through as a pre-condition for success would significantly reduce the security of success. Examples for such scenarios are those based on carbon capture and storage, clean nuclear breeder and disposal technologies, fusion, etc. The achievement of such a technological break-through would certainly be helpful, but a strategy requiring one or even several of such technological break-through's would impose an unnecessary risk of failure. Other examples are High-Voltage-Direct-Current (HVDC) grid technology (contrary to well proven HVDC point-to-point interconnections), compressed air energy storage (CAES), a hydrogen energy economy, power to gas, etc. All these options would be nice to have and would certainly be more or less useful for a sustainable future energy supply, but should not become a possible reason for failure of a scenario and a related strategy. Therefore, our scenarios are based on technologies that are already available or at least visible in form of pre-commercial plants or demonstrated full-scale prototypes. Under this condition, any technical break-through will have the role of eventually easing the way to the sustainability goal, but without endangering its achievement.

Another general aspect of any measures for sustainability is the time they need to be realized. Increasing international conflicts on fossil fuels and global climate change are threats that obviously do not allow waiting e.g. for nuclear fusion that is predicted by its advocates to be available in 30-50 years, a time span that is already beyond most actual scenario modeling. Therefore, elements of a possible future electricity supply scenario are also weighted by their capacity to take over significant shares of supply within a reasonable period of time.

4. ENVIRONMENTAL COMPATIBILITY

4.1. LOW POLLUTION AND CLIMATE PROTECTION

Most renewable energy technologies do not emit any substances during operation, and therefore are considered flagships for the reduction of energy pollutants and climate change. Emissions mainly occur due to the use of conventional energy sources during the production of the renewable power plants, but those emissions can be simply reduced by increasing the renewable share of the energy mix. Some technologies however, like power plants run with energy crops (fertilizers, pesticides, fuels for harvesting), large hydropower dams (methane from drowned regions) and geothermal power stations (carbon dioxide, heavy metals and radioactive materials from the depths), can lead to significant emissions to the environment and therefore must be evaluated critically in comparison to other options. E.g., oil from certain energy crops in tropical plantations can have a higher carbon footprint than equivalent mineral oil products.

4.2. NEW RISKS FOR HEALTH AND ENVIRONMENT

Significant new risks from new technology solutions that are supposed to be applied in a very large scale must be carefully assessed and quantified, and in case the available information is still insufficient, the share of such technologies in a scenario should be limited to a reasonable extent. E.g. after more than fifty years of commercial operation of nuclear plants, nuclear waste disposal is still unsolved, a fact that represents a severe sustainability issue. In about fifty years of operation of nuclear power, providing today less than 5% of global energy demand, at least three (reported) major accidents with severe nuclear contamination have occurred. In fact, those accidents did not happen and end someday, but are still continuing, imposing a permanent risk on society and the environment. Even “intrinsically secure” nuclear power technology would not provide higher safety, as the society around any nuclear installation is intrinsically not secure.

Energy crops applied in a scale that would be relevant for power generation would also create significant new risks related to the increased use of fertilizers and pesticides, competition with food, consumption of fossil fuels for harvesting and processing, high cost, land use and water consumption, so they were eliminated from the portfolio of suitable power sources. Only biomass waste from communities, agriculture and forestry was considered as potential source for power generation. Due to their capability to provide power on demand, biomass plants have a high value in the electricity portfolio.

An extreme expansion of wind power must also be considered as potentially harmful and certainly bears risks for the environment that must be carefully assessed. Damage among birds and bats has been reported and evaluated, while the sharp change of pressure on the wings of the windmills was identified as a serious thread for those species, leading to a possible collapse of the lungs even without direct contact of the wing and the body. The effect of sharp pressure gradients on insects has not yet been assessed at all, while the probability to find damaged insects in wind parks is close to zero, as they would literally be “blowing in the wind”.

4.3. LAND USE AND STRUCTURAL IMPACTS OF ENERGY TECHNOLOGIES

A primary guideline for scenario building was to limit the use of power technology as much as possible. Therefore, efficiency measures were considered as priority for scenario development, in order to cover only the really necessary demand. From two scenarios, both satisfying all sustainability criteria described here, the scenario with less installed power, storage and grid capacity would be selected by our target function, as it would impose a lower structural impact on the environment and would consume less material for its realization.

The land required per produced electrical kilowatt hour is very different for different power technologies. Hydropower dams in arid regions and most energy crops with an area-specific electricity yield below 2 GWh/km²/y can be considered worst cases in terms of land use for power generation. Wind parks can provide more than 50 GWh/km²/y, while PV and CSP installations in the desert can produce more than 150 GWh/km²/y. The higher numbers are comparable to the land use of coal and gas plants, if the total infrastructure needed for mining, transport and production is included in the balance. Of course, if one thinks about surface coal mining or nuclear accidents like the one in Fukushima in comparison to a wind park or a CSP plant, the different quality of land use can be even more important than the sheer quantitative comparison of numbers.

A significant footprint is also related to new infrastructures like electricity grids and pump storage. In a first place, we have allowed an expansion of the electricity grid and storage capacity (as long as a potential was available) directly proportional to the national electricity demand. This can be considered as the minimum need for this type of infrastructures. The most important parameter for this type of infrastructure is the installed capacity. In the case of storage this is the maximum power capacity the storage is able to accept and store, while the grid can be represented by its net transfer capacity (NTC). E.g. Germany at present has a NTC of about 8 GW towards its neighbor countries. However, an expansion of the German NTC to, let's say 16 GW, would not mean to install 8 GW of power interconnection at the borders of Germany only. In principle, it would mean to double the total German electricity grid, which would be a significant impact on the German environment. If the fluctuating power capacity that must be compensated by storage and grid infrastructure increases, increased conversion and transportation losses will occur. In this case an even higher power production capacity, leading to higher surplus and fluctuations, must be installed in order to compensate such losses. This positive feedback effect counteracts the principle of installing as little technology as possible and is therefore avoided in our scenarios as far as possible.

5. SOCIAL COMPATIBILITY

5.1. FAIR ACCESS TO ENERGY

An important principle of sustainability that aims to avoid national, regional and international conflicts is a fair access to energy for everybody, including present and future generations. This can be achieved only if the resources used are abundant and affordable. Finding a well-balanced mix of energy sources that will depend on the specific geography and meteorology of each country will enable most countries to achieve that goal. One of our findings is that energy in fact is not a scarce commodity. Only ideally stored forms of energy, like fossil fuels, are relatively scarce. One of the most important strategies resulting from this fact is to use renewables to the greatest extent possible, and complement them by fossil fuels only when such ideally stored forms of energy are compulsively needed. Thus, the pressure on fossil fuels can be reduced and their availability for future generations can be secured or at least prolonged.

5.2. DEPENDENCIES AND INTERDEPENDENCIES

If things become tough, neighbors that depend on each other will most likely cooperate in order to solve the problem, while independent neighbors will probably start to fight in order to get an advantage. For this reason, local, regional or national autonomy of supply was not considered as a criterion for sustainability, but on the contrary, international cooperation with the goal to tap common energy resources was.

5.3. STRATEGIC FLEXIBILITY

In order to guarantee full strategic flexibility on a pathway towards sustainability, the scenarios were built by strictly ignoring present or possible future energy policy of any kind. The scenarios are considered to be consistent, independent, first drafts of possible routes to sustainability based on scientific analysis. Only one route is usually shown, which is not little, considering it is one feasible way to sustainability. However, the energy mix shown in the scenarios can be varied within reasonable boundaries, as long as the existing natural, social or economic “guard-rails” or “crash barriers” are not violated and the target, sustainability, is achieved.

This first draft of a possible pathway towards sustainability is then handed over to policy makers in order to be evaluated, to be discussed and to provide a basis for further research and decision making. The scenarios help to find out if the goal is feasible, desirable and achievable, and what measure must and could be taken to get there. A lot of details will change in the course, and some technical break-through will perhaps ease the way, but the principles learned can and should in any case help to find a way for society even under harsh real world conditions.

6. METHODOLOGY

The pathway described by each scenario is only one of many possible variants and does not represent any optimum, as no optimization process was involved. The future target is found starting in the present and changing the supply portfolio step by step (year-by-year), trying to stay at any time clear of any guard rail limiters.

The sustainability target is narrowed down quantitatively by thresholds regarding carbon emissions (on average less than one ton per capita per year), cost (level of average electricity cost of the year 2000), security of supply (125% firm capacity compared to peak load) to mention the most important, but also by qualitative goals regarding diversification of supply, availability of technology, land use, etc. as described above. Only few parameters were considered as hard limiters (e.g. 125% firm capacity), while others were accepted if coming close to the goal and pointing in the right direction (cost of electricity of 2000 is not achieved in all countries, but in all cases, by introducing renewables, in the long-term the electricity cost is stabilized on a slightly higher level with downward trend, while in a business-as-usual reference case, electricity cost subsequently escalates to higher levels).
The process is iterated until a satisfying result is obtained, represented by a balanced set of sustainability criteria.

The available technology portfolio is limited by the existing natural resources and by economic and environmental constraints. The merit order begins with clean, in the long-term cheap, but fluctuating sources like wind and later photovoltaic power, continues with flexible and at the same time renewable but more expensive options like hydropower, biomass, concentrating solar power and advanced geothermal systems. If those forms of flexible energy are not sufficiently available on national level, they are imported. Finally fossil fuels, that are expensive in the long-term, pollutant and depletable, but ideally stored forms of energy, are considered as last option.

Existing political and regulatory constraints are strictly ignored in the modeling towards the target function. As an example, from the point of view of the year 2006, when the TRANS-CSP scenario was built, political and regulatory limiters existing then would not have opened any single pathway towards the sustainability target function. In effect, this pathway was - and in some cases still is - blocked by the existing policy in some of the analyzed countries. Therefore, ignoring political limiters finally leads to a scenario that shows one consistent pathway towards a sustainable future, which however will require political change to be achieved. In view of the scenario results, policy makers can then evaluate options to change their policy in order to achieve the sustainability goal or not, or to find variants of such a scenario that may be more appealing to them.

Besides the sustainability criteria described above, the following guard rail limiters have been considered for scenario development:

- natural resources can limit the use of energy technologies,
- power demand can limit the use of electricity sources,
- cost learning curves can increase potential electricity market shares,
- enough flexibility to follow the electrical load must be maintained at any time,

- innovation cycles and replacement of old plants opens windows for new plants,
- growth rates of renewable energy technology production capacities are limited,
- power exchange between countries is limited by the net transfer capacity,
- need for extra storage and grid capacity is avoided as far as possible.

7. DISCUSSION OF RESULTS

The results of e.g. the TRANS-CSP study are characterized by a well-balanced mix of renewable and conventional power sources (Figure **1** and Figure **2**). Wind and in the long-run also PV electricity takes the role of a cheap fuel saver that however does not contribute to firm power capacity due to its fluctuating character. In a first place, wind and PV are complemented by flexible forms of renewable energy like hydropower, biomass and CSP that are more expensive, but can fill the gaps and cover the load at any time on demand. Finally, but only for short times over the year, ideally stored fossil fuels are used to close the gaps still left by renewables. This electricity mix varies for each country according to its demand structure and the availability of renewable energy resources in the specific region. The scenario ends in 2050 with 80% renewable share, but afterwards can be easily extended to 100% following the same principles.

In some cases, where flexible forms of renewable energy are not abundant enough inside a country to replace fossil fuels, they are imported. Examples are imports of stored hydropower from Norway and concentrating solar thermal power (CSP) from North Africa to Germany.

Even under the rather conservative fossil fuel cost assumptions of the original TRANS-CSP study, it was shown that the introduction of renewable energy in the power sector without exception leads to a medium term (20 year time frame) stabilization of electricity costs in every country analyzed. In the long run (2050) renewable power becomes the least cost option worldwide.

According to the scenario, the high technical value of ideally stored forms of energy like fossil fuels keeps them in the market for very long time. Storage and grid infrastructure both have considerable impacts on the environment and face a series of acceptance challenges by the public. Firm capacity from renewable sources is rather difficult to tap, especially in Europe with its limited resources of hydropower and biomass. For incidence, the main and only reason for long-distance solar electricity imports from CSP in North Africa is in effect the need for - and the lack of - flexible and firm renewable power capacity in Europe. Using only natural gas, coal or uranium for this purpose would in the long-run offend several guard rails and sustainability criteria of the target function, like e.g. diversification and security of supply, affordability and environmental impacts.

The original study TRANS-CSP (2006) covers Iceland, Norway, Sweden, Finland, Denmark, Ireland, United Kingdom, Portugal, Spain, France, Belgium, Netherlands, Luxembourg, Germany, Austria, Switzerland, Italy, Poland, Czech Republic, Hungary, Slovakia, Slovenia, Croatia, Bosnia-Herzegovina, Serbia-Montenegro, Macedonia, Greece, Romania, Bulgaria and Turkey. The countries in the Middle East and North Africa and some Southern European countries were analysed within MED-CSP (2005), quantifying the opportunities of the Mediterranean region.

The demand of the electricity sector was derived from an empirical top-down model developed by Trieb and Klann (2006) that considers growth of population, economic development and potentials of efficiency enhancement as the main drivers for electricity consumption. According to this model, electricity consumption grows moderately until 2040 and is slightly reduced afterwards. It must be mentioned that this model only extrapolates the classical electricity sector, not taking into account possible changes of paradigm like electrical heating or electro-mobility, which could achieve major importance in the future and then would add to the results shown here (Figure **1** and Figure **2**).

The scenario is characterized by a clear diversification of resources, tapping in a first place all possible domestic renewable energy sources within Europe and in addition importing solar electricity from concentrating solar power stations in North Africa. By 2050, about 80% renewable share is achieved, electricity costs are stabilized at a reasonable level and carbon emissions are limited to the 2°C threshold recommended by IPCC, while land use of the total power park reaches about 1%.

Nuclear power is phased out by economic reasons, as the massive introduction of volatile renewable sources like wind and PV subsequently reduces the utilization of today's base load power plants to about 2000 full load operating hours per year, which does not allow for a competitive operation of lignite, nuclear fission or fusion plants in the long-term future. For similar reasons, coal plants are also submitted to increasing economic pressure.

Base load and balancing power services are taken over as far as possible by firm and flexible renewable options like stored hydropower, biomass, geothermal energy and concentrating solar power imports from North Africa using thermal energy storage and fuel backup. The primary condition for scenario development was that the net firm capacity of all power stations now and in the future must at any time be larger than 125% of the peak load that occurs once a year.

For consistency of the scenarios not only the balance of annual electricity consumption and annual supply of electricity is important (in terms of TWh/y), but also the short-term balance of load and firm power capacity available at any time during the year (in terms of GW). This condition ensures that power will at any time be available on demand. This is the reason for keeping power capacities from gas and coal rather high even in the long-term future, although their share of electricity production will be rather low. Plants using ideally stored forms of energy like gas and coal will remain for backup and emergency, but will run only for very short time over the year.

In principle, the fuel for such plants could in the long-run also come from renewable sources, if technologies like power-to-gas or synthetic liquid hydrocarbons are introduced, that already exist today. So the gas of the future used for emergency backup in a mainly renewable electricity supply system may also be produced by renewable energy. The small shares of this type of energy will allow for a relatively high cost of these sources. In the scenario, the capacity of volatile and non-flexible power plants is limited so their capacity does not exceed peak load. Thus, surpluses from wind and PV are limited to rather small shares, which is perfectly in line with such a strategy.

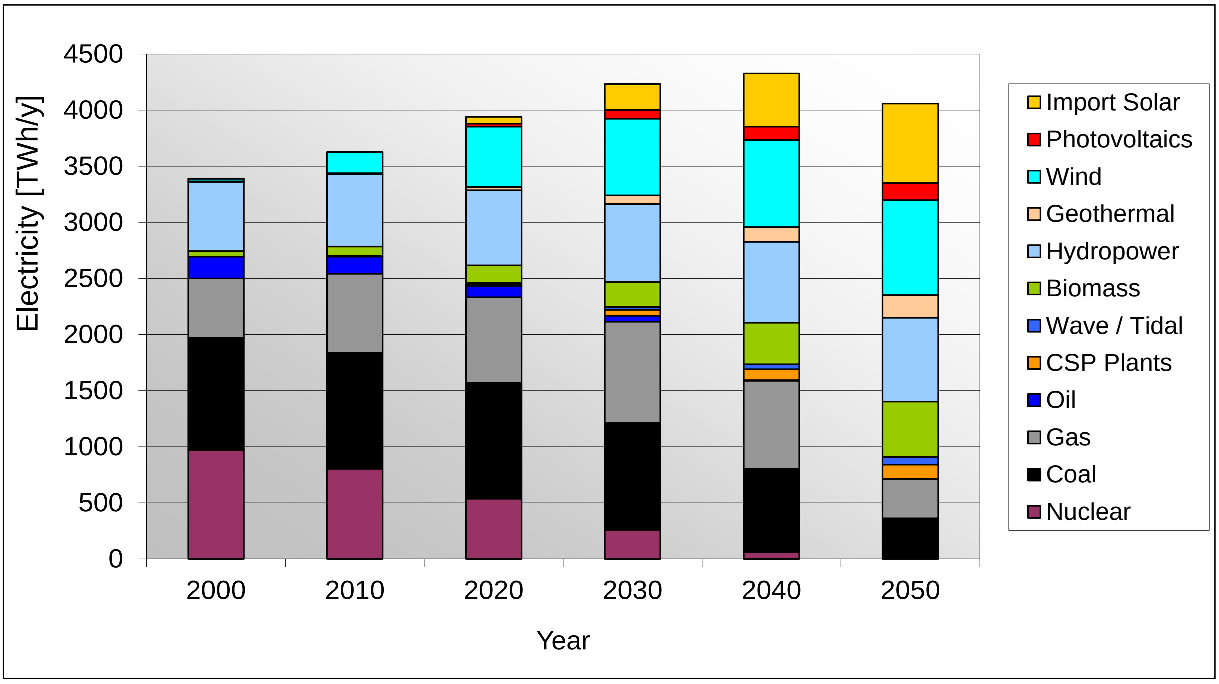

Figure 1: Annual electricity supply according to the original scenario TRANS-CSP (2006) with 80% renewable share characterized by stagnating power consumption, nuclear phase-out and solar electricity imports from North Africa to Europe.

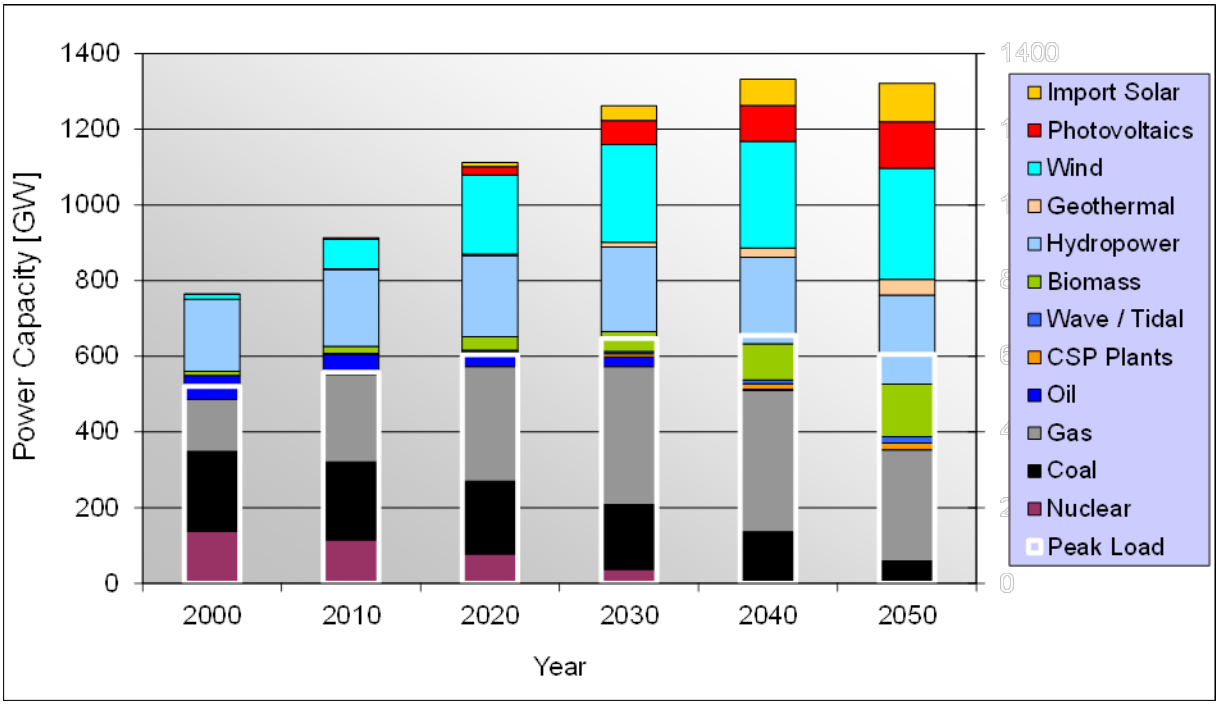

Figure 2: Installed power capacity in the original scenario TRANS-CSP (2006).

Peak load is covered at any time by 125% firm capacity. Variable and non-flexible capacity is limited below peak load in order to avoid too much surplus electricity. In such a scenario, no significant extension of storage capacity or grid transfer capacity is required, because grid operation with little power surplus and no gaps is already achieved by a well-balanced mix of technologies and sources.

The availability of firm and flexible power capacity will achieve major importance in the future electricity mix, especially if this mix is supposed to be dominated by renewable sources. E.g. Germany, like many European countries, has abundant potentials for variable renewable energy sources like river runoff, wind and photovoltaic power, but only limited potentials for easily storable sources like biomass, hydropower from large dams and geothermal power.

Under German climatic conditions there is no economically attractive potential for the installation of CSP plants. Therefore, flexible power from CSP will have to be imported from the south. The time series in winter and summer in Figure **3** show two typical situations that may occur in a future electricity mix that would be based to a large extent – in this case by about 90% – on renewable sources.

In summer, there will be little power from wind parks but high input from PV, while the other power sources will be used for base load and balancing power and will have to fill the gap between fluctuating renewable supply and otherwise fluctuating demand. Scenario 1 that will be based mainly on fluctuating sources like wind and PV will produce noticeable surplus peaks during daytime, while scenario 2 with solar power imports from North Africa will not produce considerable surplus.

In winter, wind power from onshore and offshore wind parks will deliver major shares of energy to the grid, requiring sufficient network transfer capacity from North to South and sufficient electricity storage capacity to buffer related fluctuations. On the other hand, there will be very little input from PV in this season. During peak wind supply and low demand, all other power plants will be operated at their minimum capacity or stand-by in order to be able to come into operation as fast as possible when supply from wind power is reduced. Scenario 1 will produce surplus in the order of magnitude of the peak load, while scenario 2 will not produce noticeable surpluses.

The role of CSP-imports in such a mix is to provide flexible, cost-efficient and sustainable electricity on demand. This high-quality electricity would be transported from North Africa and the Middle East to Europe via high voltage direct current (HVDC) power lines that would be explicitly build and financed for that purpose. The lines would provide renewable electricity on demand just as required at the feed-in points in Europe at a cost that would be stable for at least 40 years of operation. Another source of energy with comparable quality of supply will be electricity imported from Norway, which will mainly consist of wind power stored in large hydropower pump storage facilities and hydropower from dams released on demand for the German supply. The proportion of either one or the other solution in the future electricity mix will be determined by public acceptance, political frame conditions, environmental impacts, costs and technical restrictions.

The total installed capacity in Scenario 1 is 375 GW power plants, 40 GW storage capacity and 40 GW net transfer capacity of the grid. In scenario 2 including electricity production and transfer in North Africa, the total installed capacity would be 225 GW power plants, 28 GW net transfer capacity including HVDC links to North Africa (16 GW) and Norway (4 GW) and 8 GW pump storage and CAES. The difference of installed capacity of both scenarios amounts to 195 GW, which is more than the presently installed power capacity in Germany.

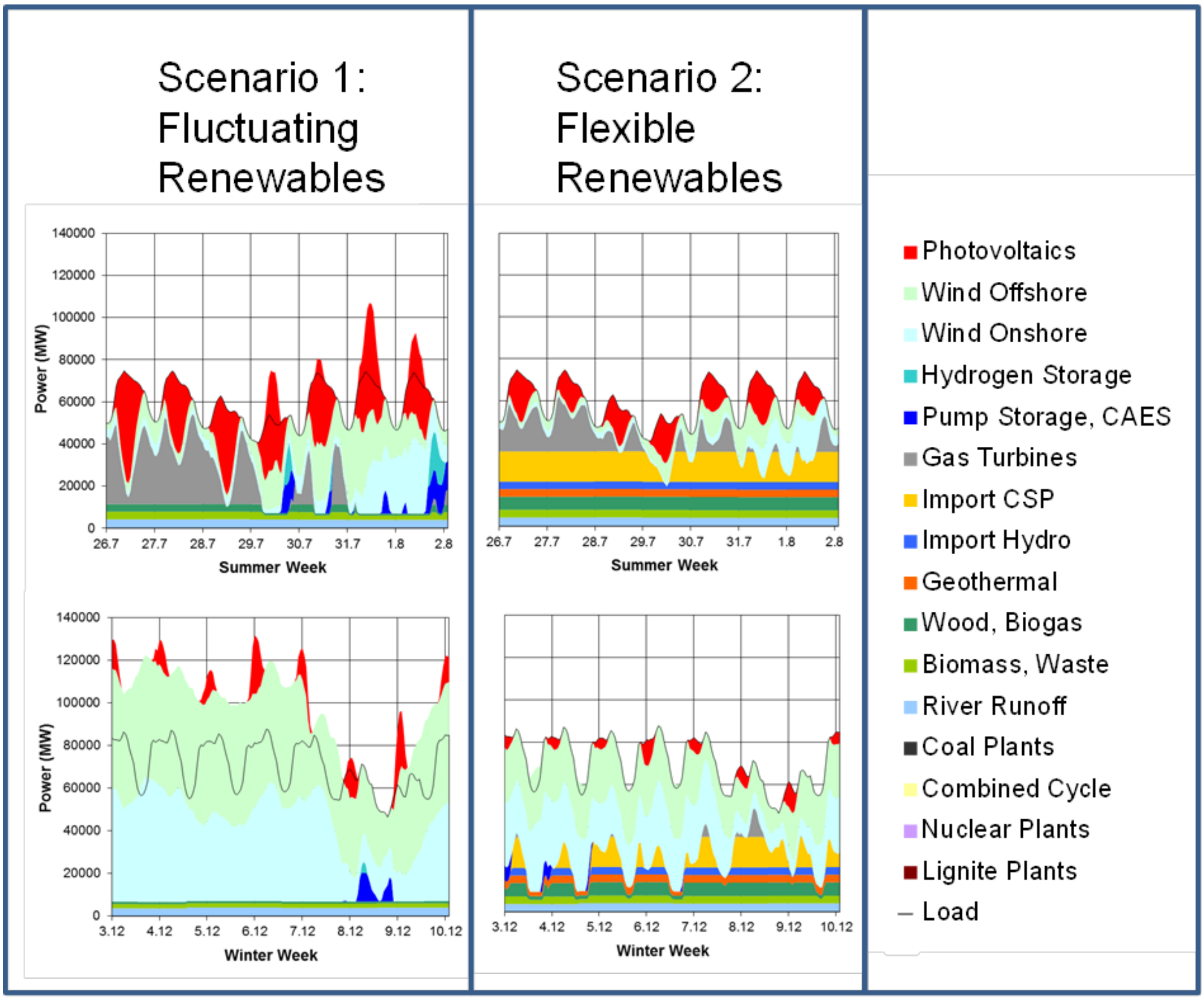

Figure 3: Two scenarios for a German power supply system with 90% renewable energy share in 2050: on the left: scenario 1 is mainly based on fluctuating domestic sources like wind and PV; on the right: scenario 2 makes use of flexible solar electricity imports from CSP plants in North Africa and hydropower in Norway. The total installed capacity of power plants, grid and storage amounts to 455 GW in scenario 1 and only requires 260 GW in scenario 2. The figure shows a selected one week sequence in summer (top) and winter (bottom) from an annual hourly time series analysis of both scenarios. Significant surplus power and thus the need for large electricity storage and grid expansion in Scenario 1 are effectively avoided in the Scenario 2 by making use of flexible solar electricity imports from North Africa via HVDC transmission.

Due to several sustainability criteria like a higher diversification of supply, much lower structural impact, higher security of success and better public acceptance, Scenario 2 with electricity imports from North Africa would clearly be the one selected by our approach.
It must be noted that this result strongly contradicts the interest of many industrial lobby groups, as it will reduce their potential future business by up to 195 GW of installed power, grid and storage capacity. However, on a planet where in about 30 to 50 years even iron, copper and concrete may become scarce a scenario with significantly lower structural demand is certainly a better option.

The criteria and methodology described here will be used for the development of bottom-up scenarios of the electricity sector of the countries analyzed in the BETTER case study for North Africa within WP3.

8. REFERENCES

International Energy Agency, IEA World Energy Outlook, Paris (2005) www.iea.org

MED-CSP (2005), Trieb, F., Schillings, C., Kronshage, S., Viebahn, P., May, N., Paul, C., Klann, U., Kabariti, M., Bennouna, A., Nokraschy, H., Hassan, S., Georgy Yussef, L., Hasni, T., Bassam, N., Satoguina, H., Concentrating Solar Power for the Mediterranean Region. German Aerospace Center (DLR), Study for the German Ministry of Environment, Nature Conversation and Nuclear Safety, April 2005. (www.dlr.de/tt/med-csp)

TRANS-CSP (2006), Trieb, F.,Schillings,C.,Kronshage,S.,Viebahn,P.,May,N.,Paul,C.,Klann,U., Kabariti, M.,Bennouna, A.,Nokraschy, H.,Hassan, S.,Georgy Yussef, L.,Hasni, T., Bassam, N.,Satoguina, H., Trans-Mediterranean Interconnection for Concentrating Solar Power. German Aerospace Center (DLR), German Ministry of Environment, Nature Conversation and Nuclear Safety, June 2006 www.dlr.de/tt/trans-csp

Trieb, F., Klann, U., Modelling the future electricity demand of Europe, Middle East and North Africa, Internal Report, DLR (2006) http://www.dlr.de/tt/institut/abteilungen/system/projects/all_projects/projektbeschreibung_med-csp/additional_reports/Demand-Model_20061128.pdf